Exploring Humanoid Robots

Technology Innovation and Design III

Jim Rauf

Evolution of Humanoid Robots

I Industrial Robots and Humanoid Robots

II Humanoid Robots History

III Humanoid Robot Technology Innovation Design

IV Market Conditions and Trends

V Costs and Affordability

VI Manufacturers

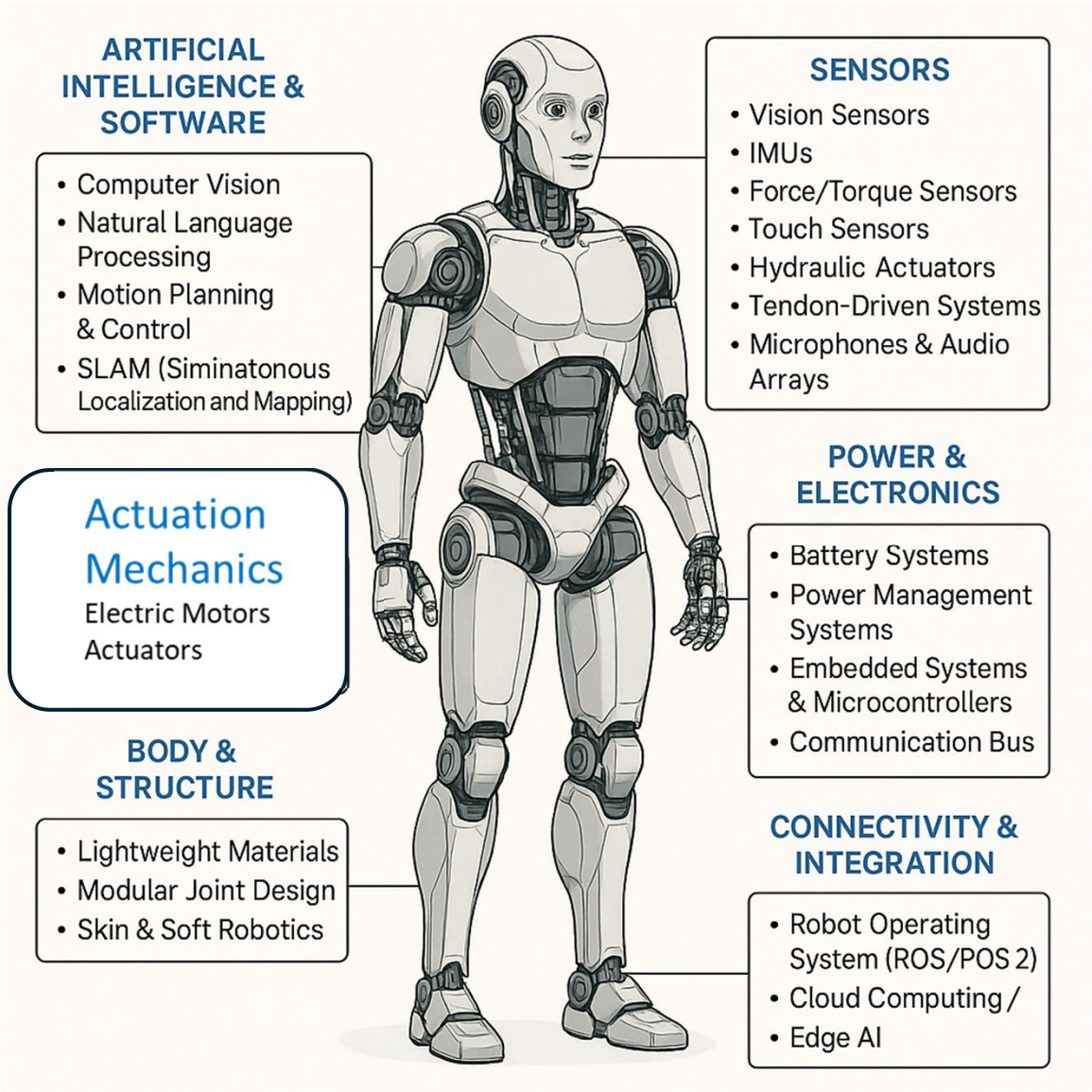
VII Effects on Society

VIII Future of Humanoid Robots

Technology

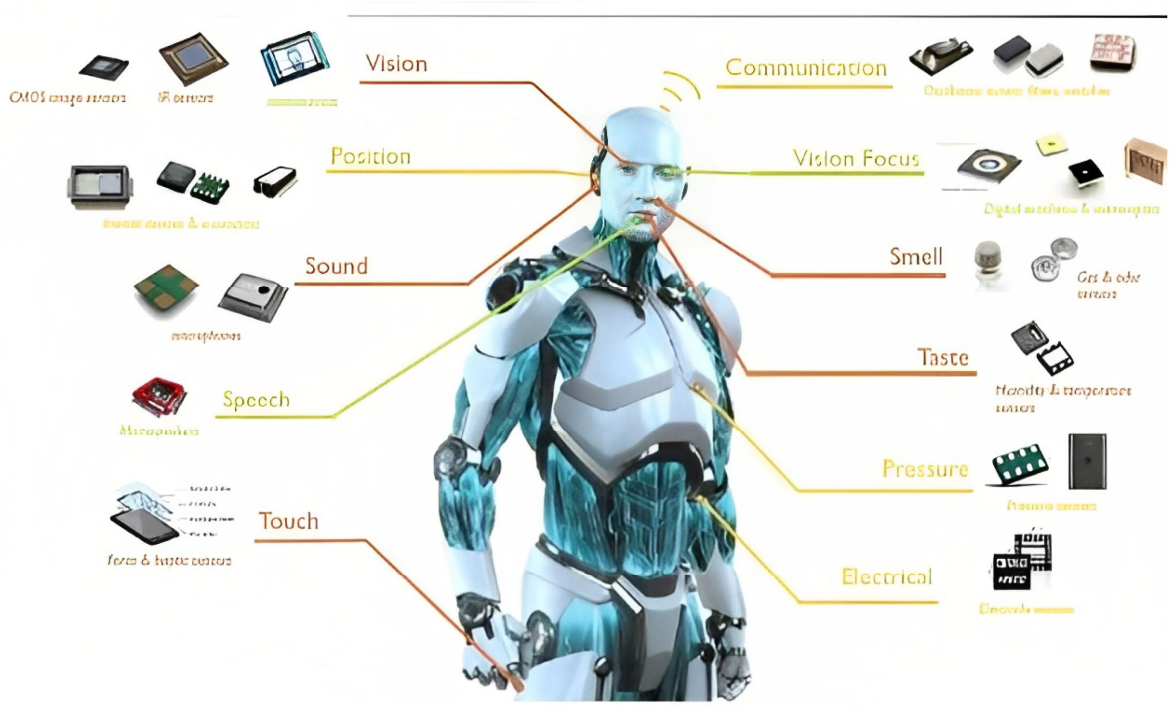
- Humanoid robots incorporate a wide array of technologies
  - Mechanical
  - Electrical
  - Software
- To replicate
  - Human-like appearance
  - Movement
  - Perception
  - Interaction

Technology


ARTIFICIAL INTELLIGENCE & SOFTWARE
• Computer Vision
• Natural Language Processing
• Motion Planning & Control
• SLAM (Siminatonous Localization and Mapping)
SENSORS
• Vision Sensors
• IMUs
• Force/Torque Sensors
• Touch Sensors
• Hydraulic Actuators
• Tendon-Driven Systems
• Microphones & Audio Arrays
Actuation Mechanics
Electric Motors
Actuators
POWER & ELECTRONICS
• Battery Systems
• Power Management Systems
• Embedded Systems & Microcontrollers
• Communication Bus
BODY & STRUCTURE
• Lightweight Materials
• Modular Joint Design
• Skin & Soft Robotics
CONNECTIVITY & INTEGRATION
• Robot Operating System (ROS/POS 2)
• Cloud Computing /
• Edge AI

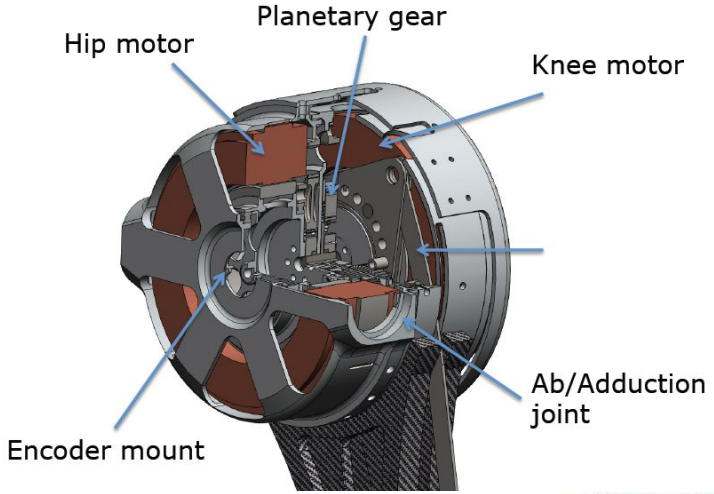
Technology Artificial Intelligence (AI) & Software

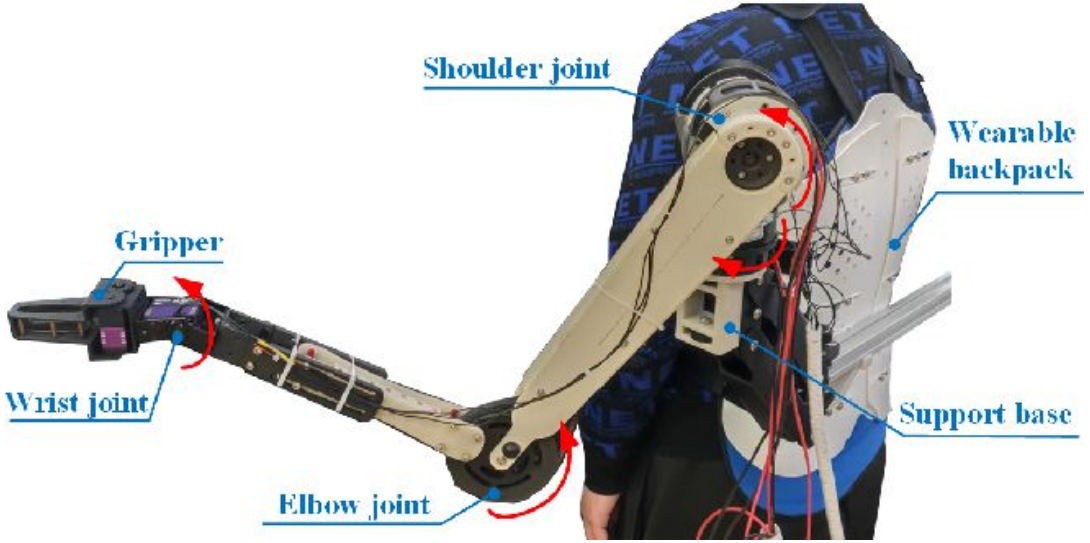
- **Computer Vision**: Object recognition, facial recognition, pose estimation, depth sensing (via cameras + AI).
- **Natural Language Processing (NLP)**: For speech understanding, translation, and conversational AI (e.g., GPT, BERT).
- **Reinforcement Learning & Imitation Learning:** For training movement, grasping, or social behaviors.
- **Motion Planning & Control**: Algorithms for inverse kinematics, trajectory planning, walking, and dynamic balancing.
- **SLAM (Simultaneous Localization and Mapping):** Helps robots understand and map their environment.



Technology Actuation & Mechanics

- **Electric Motors (Brushless DC, Servo Motors**): Standard actuators for joint control.
- **Harmonic Drive / Cycloidal Gears**: High precision gear systems for smooth joint motion.
- **Series Elastic Actuators (SEA**): Add compliance for safer and more human-like motion.
- **Hydraulic Actuators**: Used in high-force applications (e.g., Boston Dynamics' Atlas).
- **Tendon-Driven Systems**: Mimic muscle-tendon systems, used in robotic hands and faces.



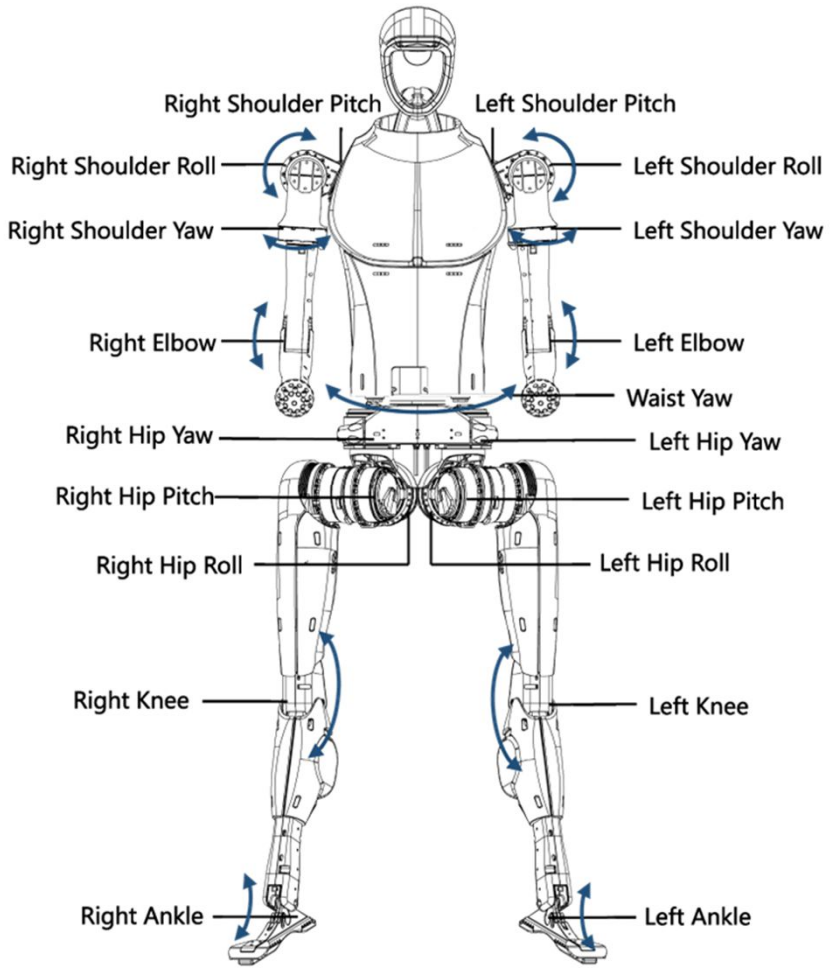


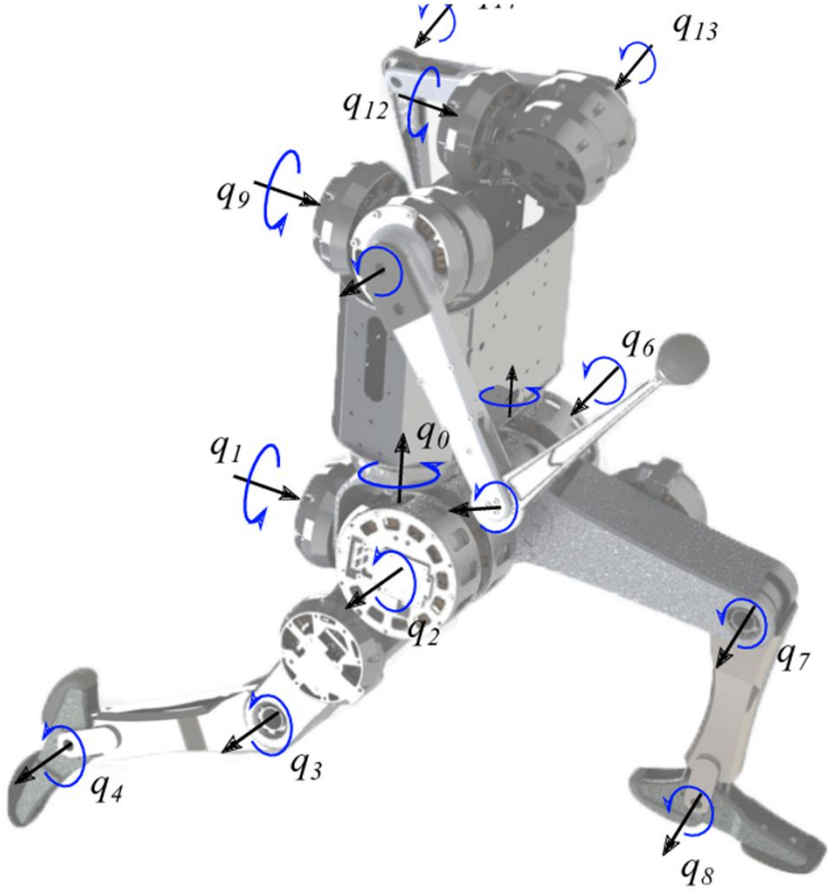
Technology Body & Structure

- **Lightweight Materials**: Aluminum, carbon fiber, and composite polymers for strength-to-weight optimization
- **Modular Joint Design**: Allows for maintenance and upgrades
- **Skin & Soft Robotics**: Silicone, e-skin, and soft actuators for human-like appearance and touch feedback

Machined from billet
Unreliable external hose routing
High part count & Bolt intefaces
Bulky multi-part box frame construction
Arterial fluid routing with integral cooling
Hose-less fluid routing
Shell and Lattice Structure for high strength/weight
Advanced Multi-material Interfaces

Technology Body & Structure Joints





Technology Sensors

- **Vision Sensors**: RGB, RGB-D (like Intel RealSense or Kinect), stereo cameras, and **LiDAR**
- **IMUs (Inertial Measurement Units)**: For balance, orientation, and movement tracking
- **Force/Torque Sensors**: At joints or end-effectors for grasping and interaction

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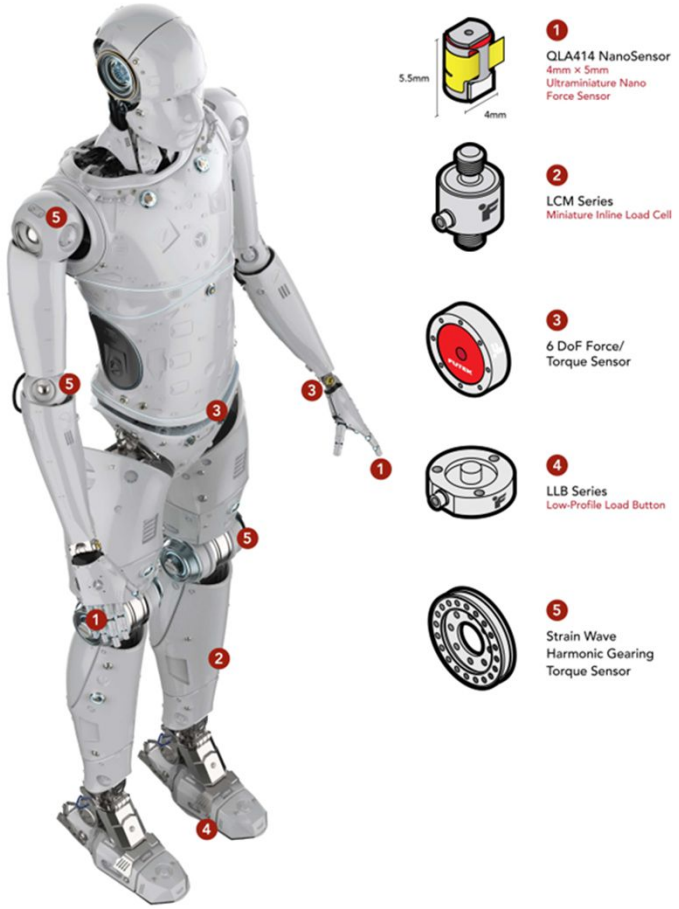
- **Touch Sensors (Tactile Arrays, Capacitive, Piezoelectric):** For detecting contact and pressure
- **Proximity and Ultrasonic Sensors**: For obstacle avoidance and situational awareness
- **Microphones & Audio Arrays**: For voice recognition, sound localization, and conversation

Technology Sensors



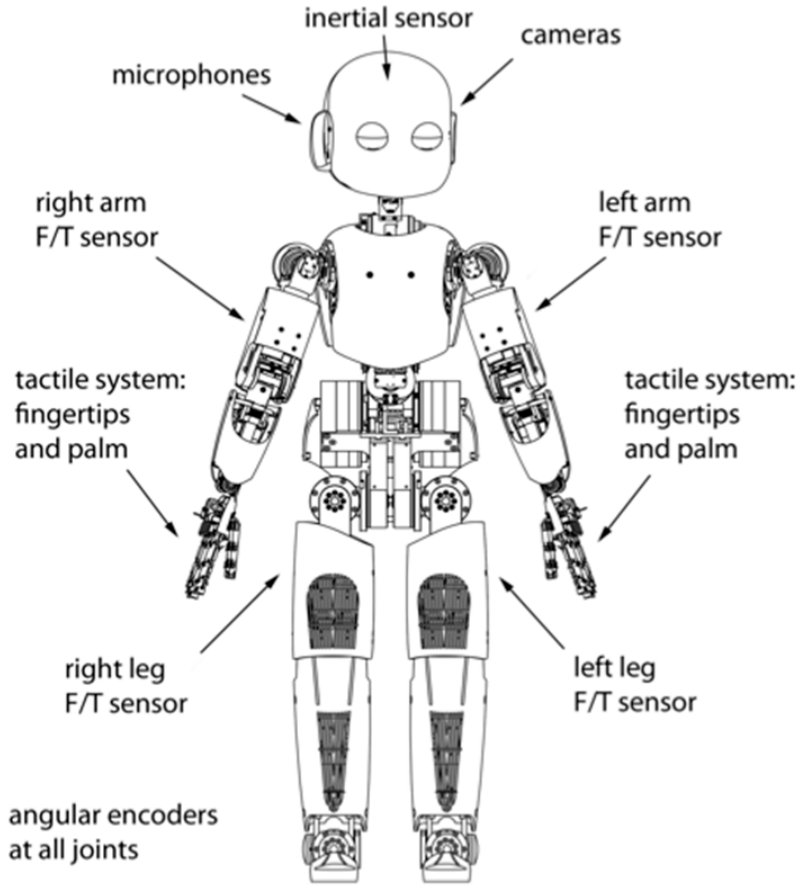
1-Force sensor(force)-fingers

2-Load cell (force)-legs

3-Torque sensor-wrists

4-Load button(force)-feet

5-Torque sensor(joints)-arms and legs



Technology Power & Electronics

- **Battery Systems**: Lithium-ion packs optimized for weight and endurance
- **Power Management Systems**: Regulate power delivery, monitor battery health
- **Embedded Systems & Microcontrollers:** Real-time control of joints and sensors.
- **Communication Buses**: For sensor/motor/ controller data exchange

Innovations as of 2024–2025

AI & Cognitive Capabilities

- **LLM Integration (like ChatGPT or Claude):** Robots now incorporate large language models for natural language understanding and reasoning
- **Multimodal Perception**: Fusion of vision, audio, and tactile input allows humanoids to perceive their environment more like humans do
- **Embodied AI Training**: Robots learn by interacting with the real world and simulated environments, enhancing adaptive behavior and motor skills

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Mechanical Design & Actuation

- **High-DOF Lightweight Actuators:** Companies like **Apptronik** and **Tesla** are creating more human-like, efficient actuators with torque sensing for compliance
- **3D-printed Muscles & Tendons**: Use of soft robotics and biomimetic materials is making movement smoother and more human-like
- **Whole-body Control Systems**: Coordinated control across limbs and torso allows for better balance, locomotion, and manipulation

Innovations as of 2024–2025

Mobility & Dexterity

- **Real-time Dynamic Balancing**: Bipedal robots now walk, run, climb stairs, and recover from pushes in real time
- **Dexterous Hands**: Companies like **Sanctuary AI** and **Figure** are advancing human-level finger dexterity for tasks like folding laundry or using tools
- **Adaptive Grasping with Tactile Feed**back: Skin-like sensors and neural nets let hands adjust grip pressure and shape on the fly

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Modular & Scalable Architecture

- **Swappable Modules (Arms, Batteries, Hands):** Enables easy upgrades and repairs, cutting downtime
- **Scalable OS Platforms**: Common robot operating systems (e.g., ROS 2) now manage everything from sensors to cloud APIs (Application Programming Interfaces)

Innovations as of 2024–2025

Power Systems

- **Next-gen Batteries & Energy Optimization**: Lightweight, high-density batteries and onboard power management reduce downtime
- **Hybrid Energy Harvesting**: Some research prototypes use kinetic or solar power assist systems to extend runtime

Innovations as of 2024–2025

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Connectivity & Cloud Integration

- **Remote Learning and Control via Cloud AI**: Robots improve over time via fleet learning, central AI updates, and simulation feedback
- **5G/Edge AI Integration**: Fast connectivity supports low-latency control and high-volume sensory data processing

Innovations as of 2024–2025

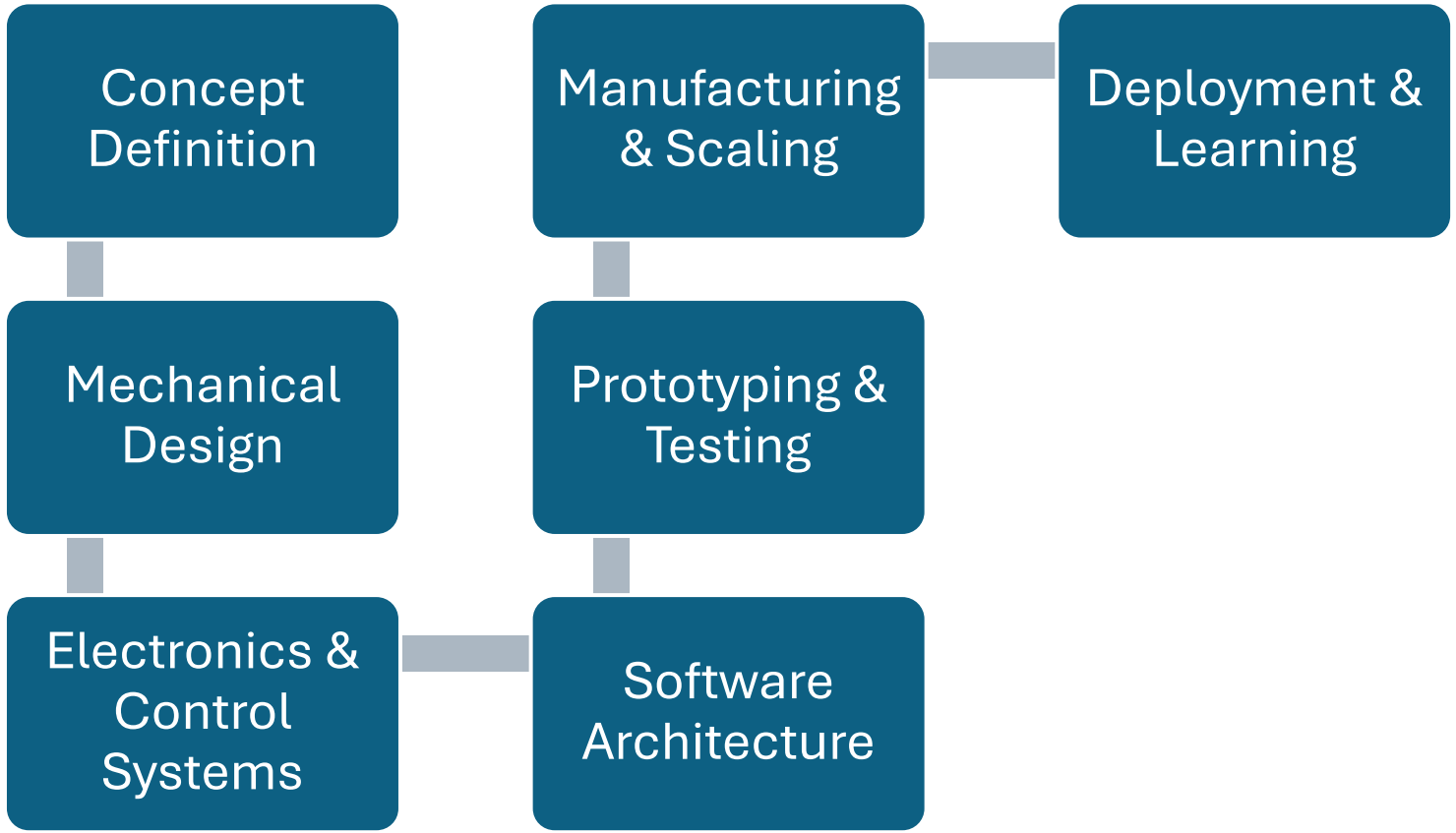
Type	Description	Applications
Service Robots	Designed for customer interaction and assistance	Hospitality, healthcare
Research Robots	Used for experimental and developmental purposes	Academic research, robotics development
Entertainment Robots	Focused on engaging users through interaction	Theme parks, exhibitions
Industrial Robots	Built for specific tasks in manufacturing settings	Assembly lines, quality control
Companion Robots	Aimed at providing companionship and emotional support	Elderly care, therapy

Innovations as of 2024–2025

Industry Deployment

- **Warehouse & Factory Work**: Humanoid robots are being trialed in logistics, machine tending, and packaging (e.g., **Figure** and **Agility’**s partnerships)
- **Elder Care & Service Roles**: Japan and South Korea lead in social robots used in nursing homes or home assistance
- **Home Robotics (early-stage): Tesla Optimus** and others target home tasks like cooking, cleaning, and item fetching

Humanoid Robot Design Design Process



Humanoid Robot Design Design Process

Concept Definition

Define the robot's core function

- Factory work
- Home assistance
- Research
- Entertainment
- Healthcare

Requirements Gathering:

Specify mobility

Strength

Dexterity

AI capabilities

Power needs

Human Factors:

Decide

Size

Weight

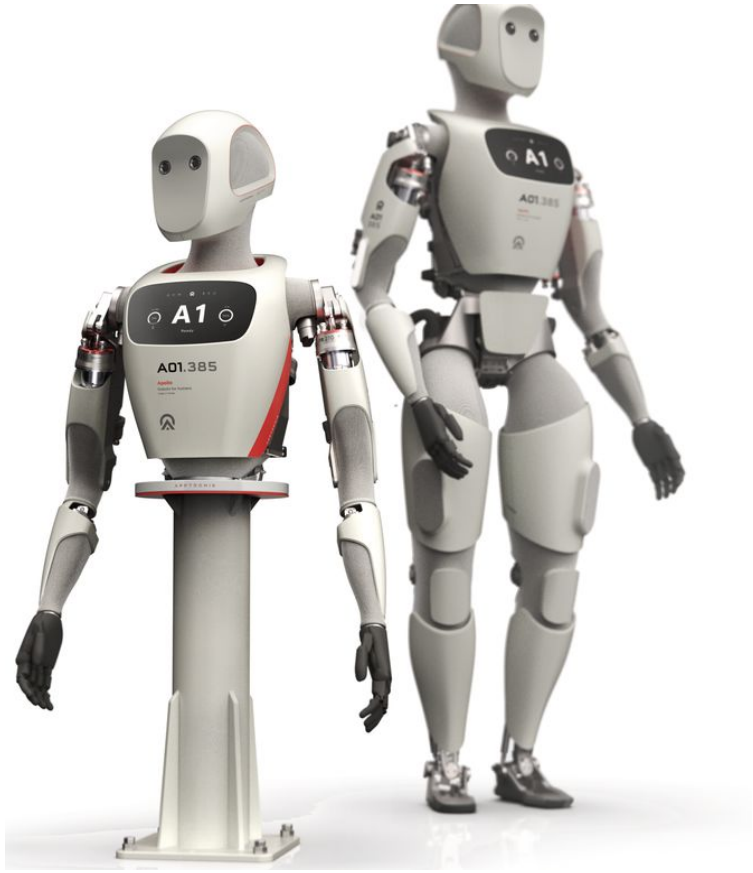
Aesthetics

Match human-like appearance?

Degrees of freedom (DoF)

- Match human-like movement?

Humanoid Robot Design Design Process



Humanoid Robot Design Design Process

Mechanical Design

Skeleton Structure:

Choose kinematic layout (e.g., number of joints per limb

Use lightweight, strong materials (e.g., carbon fiber, aluminum

Actuators:

Select actuators (servo, harmonic drive, electric motors, hydraulic, or soft actuators)

Implement torque sensors or force-feedback systems

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Joints & Degrees of Freedom (DoF):

Typical humanoids have 25–40 DoF (hands, arms, torso, legs, neck, face

CAD & Simulation:

Model the robot in software (e.g., SolidWorks, Fusion 360)

Simulate motion, stress, center of gravity, and balance.

Electronics & Control Systems

- **Sensors:**

  IMUs, force/torque sensors, LIDAR, depth cameras, microphones, tactile sensors

- **Control Boards:**

  Use microcontrollers (STM32, Teensy) or SBCs (Raspberry Pi, Jetson) for distributed control

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- **Motor Drivers & Power Distribution:**

  Develop or choose reliable motor drivers.

  Integrate a power management system (battery + safety features)

- **Real-time Control Network:**

  Use EtherCAT, CAN bus, or ROS2 DDS for reliable motor and sensor communication

Humanoid Robot Design Design Process

Software Architecture

- **Operating System**:

  ROS 2 (**Robot Operating System**) or custom RTOS

- **Motion Planning & Control:**

  Whole-body control, inverse kinematics, trajectory planning

- **Perception:**

  Visual (YOLO, OpenCV), auditory (voice recognition), and tactile feedback

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- **High-Level AI:**

  LLM integration, task planning, voice dialogue, gesture interpretation.

- **Safety & Fallback Logic:**

  Include emergency stop systems and fault recovery

Humanoid Robot Design Process

Prototyping & Testing

- **Bench Testing:**

  Test actuators, joints, and electronics independently

- **Integration**:

  Assemble full system and test walking, grasping, object detection, etc

- **Iterative Improvement**:

  Redesign mechanical parts based on wear or instability.

  Tune control loops and AI behaviors

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Humanoid Robot Design Design Process

Manufacturing & Scaling

- **DFM (Design for Manufacturing**):

  Optimize for injection molding, CNC, or 3D printing for production

- **Modularity:**

  Use swappable modules for arms, batteries, and sensors

- **Testing at Scale**:

  Use automated QA, burn-in testing, and simulated use cases

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Deployment & Learning

- **Field Trials**:

  Test in real-world environments like warehouses or homes

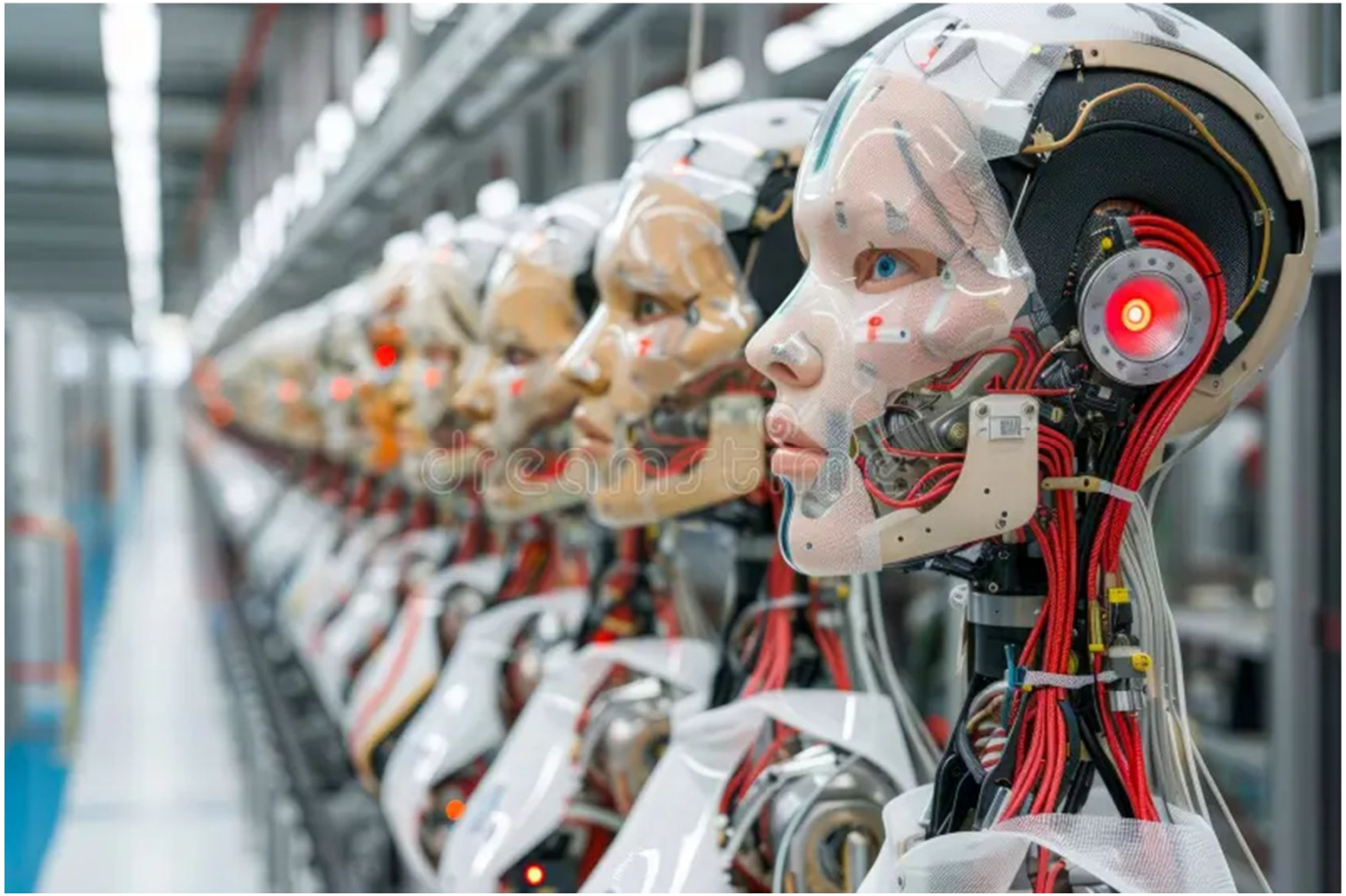
- **Fleet Learning:**

  Share data between robots to improve AI performance

- **Updates:**

  Push firmware/software updates over-the-air (OTA)

Humanoid Robot Production



Next Session

Market Conditions and Trends